

# **THE DEPARTMENT OF ENERGY'S BUDGET REQUEST FOR FY 2000**

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Committee on National Security  
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## **OPENING REMARKS**

Mr. Chairman and members of the subcommittee, I am the Director of the Lawrence Livermore National Laboratory (LLNL). The Laboratory was founded in 1952 as a nuclear weapons laboratory, and national security continues to be our central mission.

Livermore is committed to maintaining confidence in the U.S. nuclear weapons stockpile as a principal participant in the Department of Energy's Stockpile Stewardship Program. Stockpile stewardship without nuclear testing is working—but it is also work in progress. Although we recognize that the most difficult hurdles lie ahead, progress to date provides a basis for optimism that, with sustained Administration and Congressional support, the Stockpile Stewardship Program's ambitious, long-term goals are achievable.

Livermore also contributes to national programs to stem and counter the proliferation of weapons of mass destruction. We are applying our nuclear weapons expertise, together with our extensive experience in chemical and biological sciences, to the challenge of proliferation. We are involved in activities to prevent proliferation at the source, to detect and reverse proliferant activities, and to counter weapons-of-mass-destruction terrorism.

## **INTRODUCTION**

The maintenance of a safe and reliable stockpile is a supreme national interest of the United States. On December 22, 1998, Secretary of Energy Bill Richardson certified to the President that the nation's nuclear weapons stockpile is safe, secure and reliable and that there is no need at this time to conduct further nuclear tests. The Secretaries of Energy and Defense have been able to provide such assurance each year since the formal inception of the Stockpile Stewardship Program. We have been able to certify the stockpile because of the care that went into the design of the weapons in the enduring stockpile, the expertise residing in the technical staff at the nuclear weapons laboratories, and the implementation of a program of scientific activities to demonstrate weapon performance at the component level and provide reliable, integrated assessments of overall performance.

The Stockpile Stewardship Program is on schedule, and successes to date provide a basis for optimism about the program's prospects for achieving its ambitious goals. We continue making considerable headway in developing a basis for understanding aging effects in weapon materials. We are effectively using our existing experimental tools and our greatly expanded computational capabilities to address current stockpile issues through the development of a much-improved fundamental understanding of weapon performance. The stockpile is not stagnant; selected refurbishment activities already have been required. The first program to extend the stockpile life of a weapon system is on schedule. The first

unit of the refurbished W87 ICBM warhead has been processed by the Y-12 plant, and final reassembly was completed at Pantex in February 1999. The first significant modification of a weapon, the B61-11, has already entered into the stockpile.

The Stockpile Stewardship Program is also making significant strides in preparing us for the more difficult future that an ever-aging stockpile promises. The key to success is timely acquisition of greatly enhanced experimental and computation capabilities and a high quality manufacturing complex. We are proceeding with the construction of the National Ignition Facility (NIF) at Livermore and the acquisition of more powerful computers—both crucially important to the long-term success of stockpile stewardship. In January 1999, Livermore took delivery of the final elements of the 3.9-TeraOPS IBM Blue Pacific supercomputer, and scientists and engineers are already using the system for stockpile stewardship applications. This new machine, as well as the one delivered to Los Alamos this year, are the fastest and most capable supercomputers in the world. Program plans call for an increase to 10-teraOPS performance in 2001 and to even-greater capability by 2004.

Also this year, construction continued on the NIF at the Livermore site. Through your support, nearly 66% of the total funding for the NIF project has already been authorized. The NIF is on schedule and on budget. Major building construction is largely completed, and we are in the process of procuring and starting to take delivery of special equipment. This \$1.2-billion, 192-beam laser facility will provide the means for investigating the thermonuclear physics of primaries and secondaries in nuclear weapons. The NIF schedule calls for an initial capability by the end of 2001 and project completion by the end of 2003.

The Stockpile Stewardship Program has greatly benefited from strong Congressional support, effective integrated program planning and implementation, and the dedicated efforts of program personnel. We have also been fortunate that, to date, that there have been no signs of catastrophic aging in stockpiled weapons. However, vigilance is required because nuclear weapons age in very dynamic, not necessarily predictable ways. The greatest challenges still lie ahead. To succeed, stockpile stewardship requires continuing support and adequate investment over the decade it takes to implement the program.

Livermore's national security responsibilities extend beyond stewardship of the U.S. stockpile. The proliferation of weapons of mass destruction (WMD)—nuclear, chemical, and biological—is a serious threat to national security. The continuing economic and political unrest in Russia casts doubt on that country's ability to effectively secure its Soviet legacy of weapons-usable nuclear materials and WMD know-how. Regional instabilities continue to erupt around the world, which, when coupled with the desire of nation-states to acquire weapons of mass destruction, pose an increasing threat to international security. In addition, the specter of WMD terrorism looms large.

A multipronged approach is needed to protect against and counter these threats. Through a spectrum of activities, the Department of Energy and its national security laboratories are supporting U.S. arms control and nonproliferation policy, analyzing weapons activities worldwide, and providing improved capabilities to thwart WMD threats. Livermore, in particular, is making significant progress in technologies to secure weapons-usable fissile materials, to detect proliferation-related activities, and to combat WMD terrorism. For example, we completed and commissioned material protection, control and accounting upgrades at the Pulsed Research Reactor Site at Chelyabinsk-70. In addition, we developed an innovative technique that permits proper characterization of the uncertainty associated with the location and identification of seismic events. We also successfully flight-tested several remote sensing technologies for detecting chemical effluents indicative of WMD proliferation activities, and we demonstrated a biodetection instrument that is routinely capable of DNA analysis and identification in less than ten minutes.

## THE STOCKPILE STEWARDSHIP PROGRAM

The Assistant Secretary for Defense Programs has led the Department of Energy (DOE), its three national security laboratories, four manufacturing plants, and the Nevada Test Site in the development and implementation of the Stockpile Stewardship Program. It is a program designed to ensure the safety and reliability of the U.S. stockpile in an era of no nuclear testing, no new weapon development, a production complex with reduced capacity, and an aging stockpile of fewer weapons and fewer types of weapons.

Confidence in the safety and reliability of the weapons is to be maintained through an ongoing and integrated process of stockpile surveillance, assessment and certification, and refurbishment:

- **Stockpile surveillance: predicting and detecting the effects of aging and other stockpile problems.** With fewer types of weapons in the stockpile and reduced capabilities and capacity in the production complex, we need to become more proficient at early detection and identification of precursors of potential problems so that we have adequate time for thorough evaluation and action before problems affect stockpile safety or reliability. Major efforts are under way to enhance surveillance capabilities.
- **Assessment and certification: analyzing and evaluating effects of changes on weapon safety and performance.** The Stockpile Stewardship Program includes a comprehensive set of activities to address issues that arise from stockpile surveillance and to evaluate the significance of observed and predicted aging processes. Assessments provide the foundation for formal certification of the stockpile and refurbishment decisions. When modifications are deemed necessary, we must assess options for refurbishing or replacing specific warhead components as well as new production and fabrication processes and materials. Modification actions must then be certified.
- **Refurbishment: refurbishing stockpile weapons and certifying new parts, materials, and processes.** Weapon refurbishment is a particularly demanding challenge because we cannot rebuild many weapons components exactly as they were manufactured. In many cases, the materials or the manufacturing processes originally used are no longer available or are environmentally unacceptable. Production quality assurance must be provided by new assessment and certification processes that do not include nuclear testing.

### Integrated Program Management and Execution

Integrated program management and execution is critical to the success of the Stockpile Stewardship Program. The three major program elements—surveillance, assessment, and refurbishment—are tightly interconnected, as are the activities of the three laboratories, the production plants, and the Nevada Test Site. A detailed implementation plan, referred to as the “Green Book,” specifies roles and responsibilities within the program and defines the capabilities needed for stockpile stewardship without nuclear testing. As a living document, the Green Book is undergoing its fourth revision this year. It is updated and improved as the laboratories and plants continue to refine comprehensive life-extension plans for each weapon system in the enduring stockpile. These plans integrate surveillance, assessment, and life-extension manufacturing activities for each weapon system, and (to the extent possible) time-phase all activities to balance the workload.

The Stockpile Stewardship Program entails substantial partnerships among the laboratories and among the laboratories, the production plants, and the Nevada Test Site. It is an integrated effort requiring the special capabilities and the unique facilities at each site

in the complex. Livermore has major responsibilities within the program. We are the design laboratory for the W87 and W62 ICBM warheads, the B83 bomb, and the W84 cruise missile warhead. Our nuclear weapon designs are in two legs of the strategic triad and, overall, comprise three of the eight weapon systems scheduled to remain deployed in the next century.

The Laboratory also operates for the integrated complex a number of state-of-the-art experimental and computer facilities that are essential for stockpile stewardship. In addition, as one of the two nuclear design laboratories, Livermore shoulders essential responsibilities in formal revalidation and certification activities for all nuclear weapon systems in the stockpile. In the absence of nuclear testing, revalidation and certification depend on formal review of the technical assessments performed by program personnel. The process is greatly strengthened through the use of expertise and capabilities at each of the laboratories and independent evaluations—often referred to as “peer review.”

## **ACCOMPLISHMENTS—IN STOCKPILE SURVEILLANCE**

Our stockpile surveillance efforts focus on Livermore designs in the stockpile. We are preparing detailed archives of existing test data and using very modern instrumentation to obtain even more precise physical data on stockpiled weapons for use as a baseline to identify anomalies in aging weapons as they occur.

More generally, we are improving the sensors and techniques used to inspect all stockpiled weapons. For example, Livermore is developing high-resolution x-ray tomography for imaging weapon pits, solid-phase microextraction technologies for nonintrusively collecting and analyzing chemicals in sealed weapon components, and high-energy neutron radiography for nondestructively detecting small voids and structural defects in weapon systems. Working with Y-12, AlliedSignal, and Savannah River, we are also pursuing ultrasonic technologies for the nondestructive evaluation of bonds in weapon components and microsensors for evaluation of materials degradation and corrosion in weapon systems.

In addition, Livermore’s stockpile surveillance activities build the scientific base and develop capabilities to better understand aging effects in stockpiled weapons. Aging affects the physical characteristics of materials, and we must determine how these changes impact weapon safety and performance. With a better understanding of aging, our stockpile surveillance can be more predictive, making possible systematic refurbishment and preventative maintenance activities to correct developing problems.

## **Experiments, Theory, and Modeling to Better Understand Plutonium**

One of the major success stories of the Stockpile Stewardship Program is the significant improvement we are making in understanding the properties of plutonium. This is a very important issue to us—we need to understand aging in plutonium and the effect of aging-related changes on the performance of an imploding pit of a stockpiled weapon. The required capacity of the production complex depends on the anticipated lifetime of plutonium pits in the stockpile. An accurate assessment is necessary. If we underestimate the lifetime of pits, we may overinvest in facilities to remanufacture plutonium parts. If we overestimate the lifetime of pits, the nation could find itself critically short of capacity for plutonium operations when it is vitally needed. And, because of the long lead times required to increase capacity, critical decisions need to be made soon.

Plutonium is a comparatively stable material in weapons; however, its properties are among the most complex of all the elements. To study the subtleties of plutonium, we have combined advances in theoretical modeling of plutonium with the use of many advanced non-nuclear research tools made available through Stockpile Stewardship Program investments. Livermore's efforts include accelerated plutonium aging tests and subcritical experiments at the Nevada Test Site to investigate the properties of plutonium shocked and accelerated by high explosives. In addition, we carry out various types of laboratory experiments to study the microstructure of plutonium, together with computer simulations of plutonium at the atomic and molecular scales.

### ***Accelerated Aging of Plutonium***

Working with colleagues at Los Alamos, we are preparing to carry out accelerated aging tests to help us assess the performance of plutonium pits much older than those now in the stockpile. By using a mixture of isotopes of plutonium different than that used in weapons-grade plutonium (by partial replacement of  $\text{Pu}^{239}$  with  $\text{Pu}^{238}$ ), we are able to create a "spiked" material that ages about 10 times faster than the plutonium in weapon pits. Because  $\text{Pu}^{238}$  decays much faster than the replaced  $\text{Pu}^{239}$ , we will be able to accelerate the rate of self-irradiation damage, which is a key factor in aging. Through a series of sophisticated tests, we will periodically measure the properties of the accelerated-aging plutonium samples as they age up to and then beyond the oldest plutonium in the stockpile. The results can be compared with the properties of stockpile material and provide a basis for projecting the future performance of plutonium in stockpiled weapons.

We plan to make the first batch of accelerated-aging plutonium in FY 1999. A suite of experimental tests has been selected that measure changes induced by aging through use of equipment already in place at either Livermore or Los Alamos and non-nuclear experiments at the Nevada Test Site. The program is designed to make best use of the resources available at each facility. We will be monitoring potential changes in density, phase stability, and equation of state, as well as other factors. Results will be used in design analyses to assess the potential impact on the performance of weapons.

### ***Subcritical Experiments***

Livermore conducted its second subcritical experiment (Bagpipe) at the Nevada Test Site in September 1998 and its third experiment (Clarinet) in February 1999. Both experiments were very successful. They were designed to study the behavior of plutonium when it is shocked and accelerated by high explosives. Matter can be ejected from the free surface of materials that undergo shock. We are conducting a series of experiments to characterize ejecta, which is thought to affect the performance of primaries in weapons. Performance is being studied as a function of plutonium age as well as surface finish and manufacturing technique. Results will affect estimates of pit lifetime and decisions about future production of replacement pits.

Clarinet, in particular, was designed to characterize ejecta differences between new and aged plutonium using two equivalent sets of measurements. One of the experiments used a piece of wrought plutonium from an over-30-year-old sample; the second used a new piece of wrought plutonium manufactured with the same specifications. The two experiments were executed simultaneously and measurements were taken to determine ejecta particle size distributions and infer ejecta mass/velocity distributions.

### ***Laboratory Experiments and Modeling***

As a complement to the accelerated-aging work and the subcritical testing, fundamental experimental research is under way on plutonium alloys (and surrogate materials) to allow us to accurately and reliably predict the consequences of self-irradiation on the material's microstructure. These experiments are aimed at validating a predictive molecular dynamics model of radiation-induced microstructural changes, which is under development in a parallel effort. The completed code, based on fundamental physical principles, provides a complete picture of alpha-decay (and other heavy-ion) radiation damage to material lattices, as well as annealing processes and the longer-term resultant microstructural evolution. These important modeling and experimental efforts to understand plutonium aging effects are supported by Laboratory-Directed Research and Development funding.

### ***The Plutonium Facility at LLNL***

In these investigations of the properties of plutonium and its aging, the Plutonium Facility at Livermore is serving as a valuable complement to the TA-55 facility at Los Alamos. Livermore's Plutonium Facility will be participating in the preparation of accelerated-aging plutonium samples and subsequent measurements of properties. In support of stockpile stewardship, the facility is also being used to prepare plutonium samples for Livermore's subcritical tests, to investigate technologies for remanufacture of plutonium parts in Livermore-designed weapons, and to conduct other fundamental physics and engineering experiments using plutonium. In addition, as part of the DOE's nonproliferation efforts, the facility is central to the multi-laboratory Plutonium Immobilization Program to develop means for disposing excess U.S. plutonium.

### **Aging Effects on High Explosives and Other Organic Materials in Weapons**

Modern nuclear weapons consist of precision manufactured components made from highly reactive metals such as plutonium and uranium as well as organic compounds. High explosives, adhesives, and various structural parts consist of organic materials. Many of these organic materials are very stable under benign conditions. However, material breakdown occurs from exposure to radiation, higher than normal temperatures, and gases that accumulate over time in a hermetically sealed weapon environment. The aging of organic materials—particularly high explosives—is important to the safety and performance of stockpiled weapons. Through a variety of complementary activities in the enhanced surveillance program, we are investigating the effects of aging on high-explosive materials. In particular, we are enhancing capabilities to detect environmentally driven changes in aging high explosives, working to simulate aged explosives, and assessing the safety and reliability of stockpile-aged high-explosive materials. To date we have found that the high explosives used in Livermore-designed systems are very stable.

## **ACCOMPLISHMENTS—IN ASSESSMENT AND CERTIFICATION**

Assessments of the performance of stockpiled weapons and modification actions must be demonstration-based—that is, grounded on existing nuclear test data, component-level experiments and demonstration, and simulations using detailed, validated computer models. We are engaged in a balanced and integrated program of computational simulation, fundamental scientific research, and experiments. Non-nuclear experiments are used to assess weapon component performance. Together with past nuclear test results, they also are used to validate computer simulations, which rely heavily on fundamental scientific research as a source of data and a basis for the detailed physics models in the codes. Once

validated to the extent possible, weapon physics simulations guide our judgment about integral stockpile issues.

In many stewardship activities this year, we have successfully combined past nuclear test data and non-nuclear experimental results with our most sophisticated computer models and advances in theory to attain a firm scientific foundation for our assessments. Annual certification of the stockpile and dual revalidation, a very thorough multiyear evaluation of each weapon in the enduring stockpile, are fully reliant on the laboratories' assessment capabilities. Each laboratory takes novel—and at times, very ingenious—experimental approaches to examine specific issues and uses its own computer models for assessment. We are greatly encouraged by the intellectual vigor of the independent assessment approach, as well as the high level of inter-laboratory cooperation and data sharing the process is fostering. Demonstration-based assessments also underpin Livermore's W87 stockpile life extension work, which is discussed later.

### **Stockpile Certification and Dual Revalidation**

Formal review processes for certification of weapon safety and reliability in the absence of nuclear testing have been established as part of the Stockpile Stewardship Program. It is essential that judgments and decisions made by the stockpile stewards are credible among themselves, to DoD and others in the nuclear weapons community, and to the Administration and Congress. In December 1998, we completed the third annual certification of the stockpile for the President and were able to conclude that the nation's nuclear weapons remain safe and reliable.

Annual certification is based on technical evaluations made by the laboratories and on advice from the three laboratory Directors, the Commander in Chief of the Strategic Command (CINCSSTRAT), and the Nuclear Weapons Council. To prepare for annual certification, the Laboratory collects and analyzes all available information about each stockpile weapon system, including physics, engineering, and chemistry and materials science data. This work is subjected to rigorous, in-depth review by managers and scientists throughout the program.

In addition to annual certification we have developed in consultation with DoD a dual revalidation process to examine in detail over a two to three year period each warhead design in the stockpile. The W76 warhead is the first system undergoing dual revalidation and the process is nearing completion for that warhead. We have also established with DoD new procedures for recertifying weapons after life-extension refurbishment activities.

### **Hydrodynamics Experiments and Modeling to Probe Primary Performance**

Hydrodynamics testing is the most valuable experimental tool we have for diagnosing device performance issues for primaries in stockpiled weapons. Through hydrodynamics experiments conducted at Livermore's Site 300 weapon scientists are able to characterize the energy delivered from the high explosives to a mock pit, the response of the pit to hydrodynamic shocks, and the resulting distribution of pit materials when they are highly compressed. These three pieces of information are critical for baselining weapons, certifying stockpile performance, and validating hydrodynamics simulation codes.

Over the past decade, we have made tremendous advances in the development of diagnostics capabilities and experimental techniques used in hydrodynamic testing. We are now able to gather far more revealing data from hydrodynamic tests than was possible when we developed the weapons that are now in the stockpile. For example, the upgrades we have made to Livermore's Flash X-Ray facility and the development of a gamma-ray

camera have dramatically improved our ability to conduct “core punch” experiments. In these experiments, scientists use high-energy radiography to record a digital image of the detailed shape of the gas cavity inside the pit when it is highly compressed.

In 1998, the first core punches were carried out for two important stockpile primary devices: the W76 SLBM warhead (a Los Alamos design) and the B83 strategic bomb. For the Dual Revalidation Program, Livermore is characterizing the hydrodynamic and nuclear performance of the W76. As part of the effort, we worked with the Navy and Los Alamos to acquire parts and used the Flash X-Ray facility and gamma-ray camera to obtain the first ever late-time image of the gas cavity of this device (with a tantalum surrogate pit). The resulting radiograph was exceptionally high in its quality. Also, the agreement between the data and our pre-shot calculation was excellent.

Imaging the B83 was a challenge because of the device’s physical attributes. We succeeded in the first ever core punch experiment on the B83. The image was comparable in quality to earlier film-recorded core punch images taken for other devices. Again, there was excellent agreement between the data obtained and our pre-shot calculation.

### **High Energy-Density Weapon Physics Calculations and Experiments**

To determine the performance of thermonuclear weapons, we need to be able to accurately model how various types of radiation interact with their surroundings. The fundamental physical processes are particularly complex in the dynamic high energy-density conditions present during the functioning of a weapon. Materials behave very differently at star-like pressures and temperatures. Modeling performance is made even more difficult by the fact that many of the issues we need to consider are inherently three dimensional. Weapons have been designed as one- or two-dimensional objects but they age three dimensionally. Furthermore, problems that could arise in weapons (e.g., cracks or other irregularities) are also typically three dimensional. High-fidelity three dimensional modeling demands the computing power that the Accelerated Strategic Computing Initiative (ASCI) promises to deliver. It also demands experimental capabilities that can be used to generate data to validate the models.

#### ***Three-Dimensional, Time-Dependent Radiation Transport Calculations***

With the ASCI capabilities that have already been delivered to Livermore, we can now perform radiation-transport simulations that were impossible just two years ago. Over the past year, we completed the first time-dependent, radiation transport calculations in the three-dimensional geometry of an actual experiment, which was performed using the Nova laser. (The Nova laser has only very limited capability for such experiments, so our ability to generate useful validation data will greatly increase when the National Ignition Facility becomes available.) To model the experiment, roughly 500 million “unknowns” had to be solved for every time step in the calculation. The model ran for five days on ASCI Blue-Pacific Initial Delivery machine that came on-line in early 1997. Although some differences were noted, the calculated distribution of radiation over time compared well with the experimental data. We are now able to run much larger problems much faster. The most detailed stockpile stewardship calculation yet made was recently carried out on the newly-delivered 3.9-TeraOPS computer, took over 10 days to run, and provided results of much higher quality than that previously attainable.

The size and complexity of our initial three-dimensional, time-dependent radiation transport calculations are several orders of magnitude from where we need to be for more demanding stockpile stewardship calculations. The ASCI program promises—and has already delivered—considerable improvements in hardware. We also need fundamental



innovations in algorithms. Software development efforts are central to the ASCI program and to ASCI's Academic Strategic Alliances Program (ASAP), which aims to establish large-scale computational simulation as a viable methodology in science and engineering and to accelerate advances in key technology areas.

### ***High Energy-Density Physics Experiments to Validate Models***

Since the Nova laser at Livermore began operation in 1985, experiments at the facility have supported the nuclear weapons program. Nuclear detonations produce very high energy densities. Nova is able to approach such high energy densities, albeit only momentarily in very small volumes. Hence, it has been useful for generating data and validating simulation codes near—but not quite at—weapon physics conditions.

In addition to the radiation transport experiments mentioned above, we have used Nova to learn how matter behaves at high energy-densities by shock compressing materials to experimentally determine equations-of-state at high pressure. For example, in a recent series of award-winning experiments, we made some surprising discoveries about the behavior of hydrogen at extremely high pressures. We also have conducted carefully-diagnosed experiments studying turbulent flow and mixing, which is an important factor in understanding the operation of weapons. Furthermore, we have used Nova to measure the opacity of materials—how easily the material can transmit radiation—because the data is important to nuclear weapons performance.

The Nova laser will cease operations in June 1999 as we prepare to bring on-line the National Ignition Facility (NIF), which is described in more detail below. The NIF, which will be used to demonstrate fusion ignition in the laboratory for the first time, will provide much greater capability to perform the types of experiments just described—it is capable of delivering 2 million joules of laser energy (and 500 trillion watts of power) as compared to 40 thousand joules in a typical Nova experiment. Until NIF operations begin in 2001 (albeit not initially at full capability), we plan to use the Omega laser at University of Rochester to conduct high energy-density experiments. Omega is roughly comparable to Nova in its ability to delivery energy to target. In 1998 we began a series of radiation transport experiments using the Omega laser that will serve as tests of our best computer models.

## **ACCOMPLISHMENTS—IN STOCKPILE REFURBISHMENT**

Livermore is the design laboratory for four weapon systems in the stockpile: the W87 and W62 ICBM warheads, the B83 bomb, and the W84 cruise missile warhead. They are expected to remain in the stockpile well past their originally anticipated lifetimes; the W62 already has. We are developing comprehensive plans to extend the stockpile life of the Livermore-designed systems. To this end, significant effort is being expended on their surveillance, maintenance, and selective refurbishment.

In stockpile refurbishment activities, the laboratories and plants must work closely together to integrate the development of replacement components with the development of new materials and manufacturing processes. To lower costs and environmental impact, refurbishment can make use of modern production technologies and incorporate major technical advances that have occurred since the weapons were first manufactured. Our focus is on technologies that are flexible and high quality (to provide defect-free production in a capacity-limited complex) and that use modern commercial methods wherever possible.

## **W87 Life Extension Program**

The objective of Livermore's W87 Life Extension Program (LEP) has been to enhance the structural integrity of the warhead so that it may remain part of the enduring stockpile beyond the year 2025 and will meet anticipated future requirements for the system. The W87 warhead/Mk-21 reentry vehicle (RV) is a candidate for a single RV option for the Minuteman III ICBM. It is the most modern and safe U.S. nuclear warhead. It incorporates the most modern safety features: Insensitive High Explosive, a Fire Resistant Pit, and an Enhanced Nuclear Detonation Safety architecture.

The W87 LEP is on schedule. We have completed all development activities, which have included flight testing, ground testing, and physics and engineering analysis. As part of the test program, full-scale mockups of the refurbished W87 warhead were subjected to the equivalent of a thirty-year lifetime of extreme environments that a stockpile warhead might see. Then the units were disassembled and inspected for damage. High-fidelity flight tests, incorporating the latest technological advances in onboard diagnostic instrumentation and telemetry, provide added confidence in the reliability of the design modifications.

In 1998, we achieved all planned major milestones, including completion of final assessment testing and analysis and certification of production processes. No additional nuclear testing of the W87 is required to prove system reliability after the refurbishment. Assessment of nuclear performance is based on computer simulation, past nuclear tests, and new above-ground experiments that addressed specific physics questions raised by the proposed alterations and computer simulations. The first production unit was completed at the Pantex Plant in February 1999 and the final production unit in 2003.

New precedents and procedures have been established with the W87 LEP, which is the first of what promises to be a series of life extension activities within the Stockpile Stewardship Program. In many respects, the program is being managed the way development programs had been managed in the past for new warhead designs. Activities have been coordinated by a Joint DoD/DOE Working Group under the direction of the Nuclear Weapons Council. What is different is that a very extensive technical review process was established to certify the design changes in the absence of nuclear testing. It is a three-tiered review process, which has been followed at each major milestone in the program. First, Livermore conducts extensive internal review. Second, DOE conducts its own technical review, incorporating peer review by Los Alamos. Thirdly, DoD conducts a review supported by appropriate technical advisors. This review process will be repeated to certify the refurbished warheads before the first shipment later this spring to support initial operational capability (IOC). The Livermore and DOE reviews will lead to a Major Assembly Release (MAR) document and a supplement to the W87 Final Weapon Development Report. These documents release custody of the warhead to the Air Force and certify it. The DoD review will be conducted by the Design Review and Acceptance Group (DRAAG), chaired by the Air Force.

## **Advanced Design and Production Technologies**

As part of the Advanced Design and Production Technologies (ADaPT) initiative, the Laboratory is teaming with the plants to develop and provide greatly improved manufacturing technologies for stockpile refurbishment and life extension of weapon systems. We see major opportunities to introduce advanced manufacturing technology, improve production yields, and greatly lower costs in the long run. As part of our commitment, we have signed cooperative agreements with Savannah River and Pantex to develop and transfer technologies in areas of mutual interest more efficiently. We also have forged partnerships on production issues with the Y-12 and Kansas City plants, and we are

working with TA-55 at Los Alamos on plutonium-part production technologies that reduce cost, hazardous waste generation, and radiation exposure to workers.

One prominent example is the use of an ultra-short-pulse laser for precision cutting. The technology, which earned an R&D 100 Award in 1997, originated in the Inertial Confinement Fusion program at Livermore and was further developed through Laboratory-Directed Research and Development funding. In 1996, working with personnel from Y-12, we demonstrated the feasibility using lasers to cut high-value parts in the W87 warhead in a better way than prior methods. Subsequently efforts led to the design and development of a fully functional, plant-environment-compatible machine tool, the Laser Cutting Workstation. That machine tool passed acceptance testing in July 1998 and was delivered to the Y-12 plant in October 1998. The Laser Cutting Workstation has general applicability to several stockpile systems and refurbishment programs.

We also demonstrated for the first time use of the laser system as a safe and precise way for cutting high explosives. With its ultrashort pulse, the laser does not heat materials as it cuts, so it minimizes the amount of material lost and damage to surrounding material in the cutting operation. Pantex is very interested in further development of laser cutting for high-explosive applications. Additional experiments are now under way at Livermore's High Explosives Applications Facility that are testing the technology using larger quantities of high explosives. Moreover, laser cutting is widely applicable for high-precision machining and is being developed, for example, for use in the aerospace industry.

## **ACCOMPLISHMENTS—ACQUIRING NEW CAPABILITIES**

As I have already emphasized, assessments must be based on scientific and engineering demonstration to be credible. In the absence of nuclear testing, we rely on data from past nuclear tests as a benchmark, component-level experiments and demonstration, and advanced simulations for an integrated assessment of weapon performance and safety. This approach has enabled us to successfully address stockpile issues that have emerged to date. However, as the stockpile ages, we anticipate that more difficult assessment issues will arise. In addition, it is possible that, as in past cases, design and production flaws will be discovered in systems that have been in the stockpile for some time. These realities drive the Stockpile Stewardship Program's investments in much more capable experimental facilities, such as the National Ignition Facility and the Dual Axis Radiographic Hydrodynamic Test Facility, and greatly enhanced numerical simulation tools developed through the Accelerated Strategic Computing Initiative.

### **The Accelerated Strategic Computing Initiative**

The Accelerated Strategic Computing Initiative (ASCI) is greatly advancing our ability to computationally simulate the performance of an aging stockpile and conditions affecting weapon safety. Although it will take more than a decade to achieve ASCI's long term goals, the initiative is designed to deliver significant new capabilities at a steady pace throughout the decade in support of stockpile stewardship. To make the needed major advances in weapons science and weapons simulation code technology, Livermore, Los Alamos, and Sandia national laboratories are obtaining from U.S. industry dramatic increases in computer performance and information management. The ASCI program is integrating the development of computer platforms, simulation applications, and data management technologies.

We began taking delivery of ASCI platforms in September 1996 as part of the Blue-Pacific partnership between the Laboratory and IBM. The Laboratory has benefited from

the installation of a series of more capable systems since that time, leading to the delivery of the 3.9-TeraOPS system (3.9 trillion operations per second) in December 1998. We have been using the increasing capabilities with great success. ASCI Blue Pacific machines at Livermore have already performed very detailed calculations of 3-D phenomena long suspected of having a major influence on weapon performance which simply could not be addressed prior to the ASCI program. In addition, simulations on ASCI platforms are helping to provide the basis for assessments for the W76 dual revalidation effort and the program to extend the lifetime of the W87. We have also used advanced simulation codes and the enhanced computing power to study high-explosive safety issues, evaluate requirements for Inertial Confinement Fusion capsule manufacture, and greatly improve our understanding of the properties of plutonium and other materials. In addition, ASCI Blue Pacific capabilities provide a testbed to demonstrate that key algorithms in our weapon simulation codes are scalable—they will speed up as anticipated as we move to thousands of parallel processors.

### ***ASCI Blue Pacific Partnership Provides a 3.9-TeraOPS System***

At Livermore, we have just taken delivery of the final elements of a 3.9-TeraOPS system. Acquired as part of the ASCI Blue-Pacific partnership with IBM, the machine exceeded contractual performance requirements when first operated in September 1998 and hardware delivery was completed six months ahead of schedule. The machine is a hyper-cluster of 1,464 nodes hooked together by a multiple-stage hierarchical network. Each node is a 4-way shared memory multiprocessor with its own operating system and local disk. In total, the 3.9-TeraOPS supercomputer is 15,000 times faster than the average desktop personal computer. Furthermore, the machine has over 2.6 trillion bytes (terabytes) of memory—80,000 times more than the average desktop personal computer—and could store all of the books in the Library of Congress. The system includes 17.3 terabytes of local disk memory and 62.5 terabytes of global disk memory.

State-of-the-art software, provided by IBM, harnesses this hyper-cluster of shared memory multiprocessors into a single system. Results obtained so far emphasize the versatility and capability of the new platform. In the first month after delivery of the first 488 nodes (one third of the overall configuration), the supercomputer pushed back the frontiers of science in a number of areas important to stockpile stewardship: three-dimensional turbulent hydrodynamic calculations, quantum simulations of chemical bonds of thousands of atoms, molecular dynamics simulations of huge systems of atoms, and calculations of neutron flux through structures.

For example, quantum molecular dynamics calculations were performed to study the intermolecular interactions of the detonation products of insensitive high explosives—a good illustration of our efforts to achieve high fidelity models for weapon performance. Computer simulation is the preferred method for investigating these intermolecular interactions because one of the detonation products, hydrogen fluoride, is a highly corrosive material and not readily amenable to experimentation. Quantum molecular dynamics models simulate the behavior of materials at the microscopic level, the only input being the types of atoms and the laws of quantum mechanics. The computer serves as a virtual laboratory where one can follow the trajectories of atoms as electrons form and break chemical bonds. The simulations involved 600 atoms, with 1,920 electrons, described at a very accurate level of quantum mechanical theory.

### ***A 10.2-TeraOPS System in FY 2000***

The next major delivery in the partnership with IBM will be a 10.2-TeraOPS system to arrive at Livermore in FY 2000. This machine will be based on the next-generation IBM processor, node, and switch technology and will constitute another dramatic leap in performance. Besides the high peak computation rate, the machine will feature 4.0 terabytes of main memory. In addition, the system has 10.0 terabytes of local disk memory and 142.5 terabytes of global disk memory. Initial capability demonstration for this system is scheduled for March 2000 and delivery begins in June 2000.

When the 10.2-TeraOPS system is fully operational, the building in which it will be installed, Building 451, will draw more than 3.0 megawatts for power, cooling, and mechanical equipment. Building 451, formerly home for the National Energy Research Supercomputer Center, is undergoing necessary modification, including a doubling of the power to the building, replacement of air conditioning units, and extension of the computer floorspace by 8,000 square feet. Siting preparation for the system will be complete by June 1999.

### ***The Terascale Simulation Facility (TSF)***

The Terascale Simulation Facility (TSF) is about creating a simulation environment rather than just a very large, but traditional, computer center. The change in concept from “computing” to “simulation” is fundamental. The latter entails the development of a seamless partnership between the ability to generate terascale quantities of data and the ability to assimilate the information and make it accessible to the human eye and mind. The scientific applications being developed today promise an unprecedented level of physical and numerical accuracy. This level of accuracy and a sophisticated supporting environment to visualize simulation experiments are required by ASCI for stockpile stewardship to succeed. Simulation, in this sense, which includes detailed visualization, represents a fundamental conceptual shift that dictates the scope and timeline for the proposed TSF.

Expansion of Livermore’s computing power beyond the 10-TeraOPS platform will require such a new facility. The technical objective is to construct a complex to house and coordinate two complementary elements: (1) the most advanced computers available, aggregated in configurations such that their capability, physical size, and power requirements will be unequaled outside of the Stockpile Stewardship Program; and (2) tools for the management, transmission, and comprehension of the vast data sets generated, referred to as Data and Visualization Corridors. Plans for the TSF have been developed and a Conceptual Design Report has been approved. Construction requires a FY 2000 line item authorization of \$8.0 million. The estimated total cost of the facility is \$83.5 million and, with timely funding, TSF will be completed late in 2004. About 24,000 square feet of the machine room (of the 48,000 square feet planned) will be available and fully equipped to accept an ASCI-scale system as early as August 2002.

Design of the TSF is driven primarily by power and space requirements for future generation ASCI-scale computers. Between of 6 and 8 megawatts are required to run the system and an additional 4 to 5.5 megawatts are required for cooling. The building will also house the growing staff of computer and physical scientists that support the computers or work on research and development projects such as the Data and Visualization Corridors necessary for assimilating terascale data sets.

### ***The Assessment Theater***

ASCI applications use extremely high-resolution (and growing) models—as large as tens of billions of cells—and generate vast amounts of raw data that can overwhelm scientists. The ASCI Problem Solving Environment project entails activities at the laboratories and with university partners to improve visualization and data management tools. This area is broadly called Data and Visualization Corridors (or DVCs). We are combining high performance storage and networking with a visualization architecture that allows interactive exploration of large quantities of data. Tools are being developed to interactively navigate the generated data and select subsets to analyze. Improved visualization of ASCI-generated data is offered by Livermore's new Assessment Theater, a user interface of the DVC. The theater includes state-of-the-art projectors to achieve extremely high resolution and superior image quality on a 3,840 x 3,072-pixel screen (to increase to 6,400 x 3,072 in FY 2000). The Assessment Theater is connected to the Livermore Computing complex via the Laboratory's fiber optics infrastructure. The theater provides opportunities for weapon scientists to visualize the results of ASCI calculations and for visualization researchers to experiment with capabilities that are among the best in the world.

### **The National Ignition Facility**

Construction is under way at Livermore of the National Ignition Facility (NIF), a \$1.2 billion facility housing a 192-beam laser and associated experimental capabilities. The NIF is a cornerstone of the Stockpile Stewardship Program. It will be the only facility capable of well-diagnosed experiments to examine fusion burn and study the thermonuclear properties of primaries and secondaries in nuclear weapons. Advanced computer models being developed for stockpile stewardship need to be tested in the physical conditions that only the NIF can provide.

Groundbreaking for the NIF, which will be by far the world's largest laser, occurred in May 1997. I am pleased to report that NIF construction is on budget and on schedule for completion in 2003. If you tour the Livermore site this month you would see the completed football-stadium-size building frame. In less than three years from now, there will be a state-of-the-art laser facility already contributing to stockpile stewardship after the first 8 laser beams have been installed.

Procurement of special equipment is under way, building on critically important partnerships forged with U.S. industries to ensure that equipment based on the advanced technologies needed for the NIF can be delivered on budget on time. In particular, partnerships with industry have been pursued to develop mass-production techniques and assure the production quality of large-aperture, high-precision optical components. Enabling technology advances range from methods for rapid growth of superior quality crystals that weigh over 500 pounds to interferometers that can measure the accuracy of optical surfaces to about the width of an atom.

New production lines have been installed in companies in Fremont, CA, Duryea, PA, Middlefield, CN, and Richmond, CA, that will mass produce at very reasonable cost the large, high-precision laser glass needed for the NIF. The new manufacturing processes being used to support the NIF project will reduce the cost of large, precision optics for other applications by a factor of three and will increase production capacity by more than a factor of ten. More generally, with about 75% of funding planned to go to industry, the NIF project is also broadly affecting companies involved in integrated-circuit manufacturing, computer controls, diagnostics, power system components, high-voltage technology, high-speed digital transmission, and precision parts fabrication. The new

technologies and processes being developed will be available to our industrial partners for a wide range of commercial and DoD uses after NIF needs are met.

We are partnering with the French on laser technology underpinning our respective projects in a way that reduces the risk of technological problems for future lasers. The French are currently constructing an 8 beam laser and planning larger systems with technology similar to that of our NIF. Our partnership has been critical to establishing and meeting the goals for both nation's laser projects. The British are also considering more active participation in NIF activities.

Through your support, nearly 66% of the total funding for the NIF project has already been authorized and appropriated. To keep the NIF on schedule and within cost, \$248.1 million in construction funds need to be obligated in FY 2000. In addition, \$5.9 million in operating funds (included in the Inertial Confinement Fusion Program request) are needed. In terms of overall budget, over 87% of the funds will be committed by the end of FY 2000. The NIF schedule calls for an initial capability by the end of 2001. Weapon physics experiments will be conducted using the first bundle of 8 laser beams to be installed, which will provide a capability equivalent to approximately twice that of Nova. Half of the 192 beams will be available for use in experiments at the end of 2002 and project completion is scheduled for the end of 2003.

The NIF construction has proceeded on schedule because the full funding requested has been provided in a timely fashion. To prepare for NIF operations, certain Inertial Confinement Fusion (ICF) Program activities, such as preparing the means for making cryogenic targets for NIF experiments and training the first group of operators, must begin in 2000. The required ICF operating budget has been planned to grow as the NIF nears initial operations. This funding will be critical to effective utilization of the facility.

We are very much looking forward to the opportunity to use the NIF to achieve fusion ignition and burn in a controlled laboratory setting. To succeed will be both a remarkable achievement and meaningful indicator that stockpile stewardship is working. Like the design of a nuclear weapon, fusion in the laboratory is an integral experiment that tests the skills and resourcefulness of the physicists and engineers who will be the nation's stockpile stewards in the future. It will measure success in combining advanced simulation and experimental techniques. Success in fusion ignition experiments will also greatly boost the value of the NIF as tool for laboratory experiments to address real stockpile problems and study the physics of nuclear weapon primaries as well as secondaries.

## **HALTING THE PROLIFERATION OF WEAPONS OF MASS DESTRUCTION**

The proliferation and potential use of nuclear, chemical, and biological weapons (collectively referred to as weapons of mass destruction, or WMD) threatens the security of the nation and the world. As Secretary of Defense Cohen has said, “the proliferation of weapons of mass destruction presents the gravest threat that the world has ever known.”

The breakup of the Soviet Union brought an end to the bilateral tensions that dominated U.S. national security policy for decades. However, the economic and political instability in Russia jeopardizes that country’s ability to secure its legacy nuclear materials or assist former Soviet weapons scientists transition to self-sustaining nonweapons work. At least 20 countries, some of them hostile to the U.S., are suspected of or known to be developing WMD. In May of last year, India and Pakistan came out of the “nuclear closet” and, in doing so, shook the foundations of the global nonproliferation regime. In addition, the increasing potential availability of WMD materials and WMD know-how makes terrorist acquisition of such weapons frighteningly possible.

### **Livermore’s Nonproliferation Program**

Livermore is applying its nuclear expertise, developed through its past work in nuclear weapon development and testing and through its continuing stockpile stewardship responsibilities, to the challenge of nonproliferation. Because the threat of proliferation is not restricted to nuclear weapons and in response to recent legislation calling for enhanced U.S. capabilities against WMD proliferation and terrorism, we are also developing the technologies, analysis, and expertise needed to help stem the proliferation of chemical and biological weapons. These activities build on the Laboratory’s large investment in chemical and biological sciences. In addition, we have established a Center for Global Security Research to bridge the gap between the technology and policy communities and explore ways in which technology can enhance international security.

Livermore’s program in nonproliferation, arms control, and international security (NAI) is tackling the problem of WMD proliferation across the entire spectrum of the threat. We are involved in activities to prevent proliferation at the source, to detect and reverse proliferant activities, and to counter WMD terrorism. Different approaches are needed to address the threats posed by the different “proliferation players.” Cooperative projects can be used to engage weapons states like Russia. However, face-to-face cooperation is an unlikely prospect with determined proliferators and effective remote monitoring technologies are clearly needed. The detection challenge is even greater with terrorists, placing a premium on rapid identification and response technologies.

### **Preventing Proliferation at the Source**

We are working with the states of the former Soviet Union in numerous activities to secure weapons-usable nuclear materials and to prevent the spread of WMD technologies and expertise from these states.

#### ***International Nuclear Material Safeguards***

Protection of nuclear materials is the last bastion against the spread of nuclear weapons, since basic nuclear weapons technology and knowledge are readily available to a determined proliferant. The security of legacy Soviet nuclear materials (and weapons) is critical to the security of the U.S. The Laboratory is contributing to U.S. efforts to help Russia improve the protection, control, and tracking of its fissile materials through the DOE



Material Protection, Control, and Accounting (MPC&A) program. Likewise, it is in the best interests of U.S. national security to help former Soviet weapons scientists develop self-sustaining nonweapons applications for their weapons-related expertise, capabilities, and facilities.

MPC&A activities are taking place at more than 50 sites throughout the former Soviet Union. Livermore has the lead at ten MPC&A sites, including Chelyabinsk-70 (one of the former Soviet nuclear weapons design laboratories). In May 1998, MPC&A upgrades at the Pulsed Research Reactor Facility at Chelyabinsk-70 were completed and formally commissioned. The Laboratory is also working with the Northern and Pacific fleets of the Russian navy and the Murmansk Shipping Company to improve the protection of fresh, highly enriched reactor fuel for their nuclear-powered vessels. This work involves direct interactions with the Russian Ministry of Defense (an activity that would have been inconceivable during the Cold War). We have completed site characterizations and are implementing necessary upgrades in both physical security and safeguards process.

In addition, we are participating in DOE's new Second Line of Defense program, designed to curtail the illicit transport of items of proliferation concern from Russia. We are working with the Russian customs service to equip particularly vulnerable border crossings with radiation detection equipment. Our initial focus is on a port on the Caspian Sea and Moscow's Sheremetyevo International Airport complex. In October 1998, the Second Line of Defense program completed the equipping of the airport complex with Russian-manufactured detection equipment; the first detection (a mildly radioactive bit of metal) was made less than an hour after the equipment was in place. Also in October 1998, radiation detection and identification equipment was installed at the Astrakhan seaport.

We are working to extend MPC&A beyond Russia. In collaboration with Los Alamos and Sandia, we have installed an MPC&A Demonstration Facility at the China Institute of Atomic Energy in Beijing, China, to demonstrate the use of up-to-date technology for the protection and tracking of nuclear materials. The hope is that this hands-on facility will help establish a *de-facto* new standard for the protection of weapons-usable nuclear material in China.

### ***Initiatives for Proliferation Prevention***

The Initiatives for Proliferation Prevention (IPP) joins DOE laboratories, Russian institutes, and U.S. commercial partners in developing technologies that can be commercialized. The goal of the IPP Program is to develop commercially viable, nonmilitary opportunities for former Soviet scientists previously engaged in the development, testing, and manufacture of weapons of mass destruction. More than 300 projects have been initiated since the program began in 1994; we are currently collaborating on 50 such projects, which support nearly 1000 former Soviet weapons scientists. Technologies developed include superplastic forming processes for aluminum and alloy compositions, high-efficiency low-cost absorbents for environmental cleanup, and embedded software for future computer chips. Commercial partners include Boeing, Intel, Pratt and Whitney, as well as smaller businesses. Our scientists play a key role in helping their Russian counterparts establish commercial connections and mentoring their interactions with potential industrial partners. The program is unique among the various efforts to address the "brain drain" problem in that it directly involves U.S. industry, pursuing only those projects which industry believes have potential. Indeed, once beyond the initial phase, IPP projects require industry to make an in-kind or cash investment equal to that of the DOE. By helping the former Soviet institutes transition to self-sustaining commercial enterprise and thereby removing emigration incentives for highly skilled

scientific and technical people, programs like the Initiatives for Proliferation Prevention are an essential element of U.S. national security and nonproliferation strategy.

### ***Nuclear Cities Initiative***

The Nuclear Cities Initiative is a key new nonproliferation effort to help to develop alternative, commercial work for Russian scientists who have been engaged in the Soviet and Russian nuclear weapons programs. We want to keep Russian expertise from seeking employment abroad. The initiative is a joint program between the U.S. and MINATOM. Within the MINATOM complex there are 10 closed cities that were fully devoted to the nuclear weapons program of the Soviet Union. With the dramatic reduction in the number of nuclear weapons through various treaties and the current financial problems of Russia, MINATOM is preparing to dramatically reduce the workforce devoted to maintaining the Russian nuclear stockpile at these closed cities and apply the people, and some buildings and facilities, to commercial purposes. An estimated 50,000 new jobs need to be developed in the commercial sector in these cities to employ the personnel that will be separated from the weapons program. Through the Nuclear Cities Initiative we will work with the MINATOM institutes in the closed cities and the emerging city governments to develop business development centers and encourage corporate investment in jobs in the cities.

### ***Plutonium Immobilization***

For the disposition of plutonium from dismantled U.S. nuclear weapons, we are continuing the development and demonstration of systems to bisect pits and remove the plutonium and then convert the plutonium metal into plutonium oxide suitable for immobilization or reactor burning. Livermore developed both the pit bisector, a chipless method for opening weapon pits, and the hydride/oxidation (HYDOX) process for converting plutonium metal to plutonium oxide. This past year, we completed bisector demonstrations on seven U.S. pit types and upgraded the bisector that will be used by Los Alamos as part of the Pit Disassembly and Conversion (PD&C) demonstration line. For the HYDOX process, we demonstrated a hydride-nitride cycle approach that is faster and uses only a small amount of hydrogen, significantly enhancing process safety and decreasing the number of HYDOX systems required in the PD&C plant.

Livermore is the technical lead for DOE's multilaboratory Plutonium Immobilization Program. We are developing the process line for titanate-based ceramic (the preferred waste form selected by the Office of Fissile Material Disposition) and engaged in detailed testing of the ceramic for repository acceptance. We are also performing a design-only conceptual design review for a ceramic processing plant, which should lead to construction design in FY 2000 and plant operation in FY 2006.

Livermore also leads DOE's efforts to engage the Russians in plutonium immobilization activities that parallel those in the U.S. The objectives are to allow the Russians to gain an understanding of the immobilization technology and to provide an option for an in-country capability for industrial-scale stabilization and immobilization of Russian impure excess weapons plutonium at one or more of the three plutonium processing sites in Russia. R&D for this project builds on the work done for the U.S. plutonium immobilization program.

### ***Technical Support of Arms Reduction and Test Ban Treaties***

Livermore expertise in nuclear materials and nuclear detection is applied to develop the technologies needed to support current and future arms reduction, nonproliferation, and test ban treaties. We are heavily involved in transparency and verification efforts for a wide range of warhead dismantlement and fissile material activities, including warhead

dismantlement transparency, mutual reciprocal inspections, Mayak (Russian) Storage Facility Transparency, IAEA inspections, highly-enriched uranium (HEU) purchase transparency, and excess fissile material storage. A major challenge to dismantlement transparency (and critical to any future agreement limiting nuclear warheads) is the need for technologies that reveal enough information to verify that the inspected contents are of weapons origin without revealing design information. We have developed a new method to verify the presence of weapons-grade nuclear material without revealing sensitive information. Our Pu600 technique measures the ratio of plutonium-240 to plutonium-239 to determine whether or not the inspected material is of weapons grade. However, it does not reveal its isotopic ratio measurement (the Russians consider information about the isotopics of their material to be highly sensitive) but merely gives the inspector a yes/no report. We successfully demonstrated this technique to the Russians and the IAEA at Livermore's Superblock in December 1997 and in Obninsk in March 1998.

The nation's commitment to no nuclear testing has profoundly affected the way the U.S. maintains the safety and viability of its nuclear weapons stockpile. At Livermore, we have an ongoing effort to study the issues affecting the long-term maintenance of foreign nuclear weapons stockpiles in the absence of nuclear testing. This research helps to elucidate important differences between the specific set of U.S. technical stockpile stewardship issues and the stockpile issues affecting other declared nuclear weapon states. Careful accounting for these differences can promote better understanding of activities observed at foreign test sites. This improved understanding can help resolve questions about these foreign nuclear weapons programs and about their governments' level of commitment to international arms-control initiatives.

Monitoring of a comprehensive test ban is technically very challenging. It must take place against a background of thousands of benign events each year and requires the gathering and analysis of regional seismic signals (as opposed to the teleseismic monitoring, which was adequate for previous high-yield test ban treaties). Regional monitoring is difficult because of the complicated structure of the earth's crust through which the seismic waves travel. With an initial focus on the Middle East and Russia, we are mapping regional variations (on the scale of hundreds of kilometers) in seismic wave propagation. We are also developing corrections to processing algorithms so that event detection, location, and identification are accurate and uncertainties are characterized properly. Working with Los Alamos and Sandia, we are building a large database of regional ground truth and algorithm corrections that will be available in real time to the event-processing pipeline at the U.S. National Data Center and later to human analysts. During 1998, we developed a key methodology for representing the algorithm corrections—a process called modified kriging. Kriging is essentially an interpolation technique, and our modification allows for the tracking of uncertainty levels associated with event location and event identification.

## **Detecting WMD Proliferation**

All proliferation activities leaves clues—chemical effluents, materiel movement, and so forth. The technical challenges are enormous—monitoring a huge number of suspect sites around the world for tiny clues to WMD proliferation as proliferants engage in increasingly sophisticated denial and deception measures. We are collaborating with other DOE national laboratories in the development of novel multiwavelength passive and laser-based schemes for detecting and identifying trace amounts of “fingerprint” chemicals at a distance. We also recently embarked on a new initiative to develop data analysis tools to speed and improve the integration of massive amounts of different types of data.

## ***Remote Monitoring and Data Exploitation***

At Livermore, we are developing several long-range standoff sensors capable of measuring trace amounts of airborne effluents that are indicative of the processes occurring within a suspect facility. Instruments under development include advanced mid-infrared lidar systems for active detection of chemical effluents, an echelle grating spectrometer, and a hyperspectral instrument. Particularly successful this past year were flight tests of our hyperspectral infrared imaging spectrometer (HIRIS). HIRIS operates in the long-wave infrared and is based on an imaging Fourier-transform spectrometer. It provides both spectral and spatial information simultaneously, allowing a single instrument to serve the functions that have previously been tasked to separate instruments. In the past year, the prototype instrument was flown in several recent airborne collections on controlled releases at the Nevada Test Site and on domestic industrial facilities. These experiments benchmarked the signal-to-noise performance of HIRIS with respect to predictions and elucidated challenges inherent in plume detection and location, clutter rejection, chemical species identification, and release quantification. Algorithms are under development to address all of these issues.

New, more capable remote sensing systems would facilitate the monitoring of extremely difficult nonproliferation agreements (e.g., the chemical and biological weapons conventions) and would also be a valuable tool for monitoring foreign nuclear programs. However, the value of new instruments like HIRIS depends, in large part, on how well their data can be incorporated into expert assessments. Livermore is developing prototype tools to assist analysts in interpreting multi- and hyperspectral data in conjunction with other available data sources. Such tools are needed to help analysts interpret “chemical snapshots” of a time varying, spatially distributed WMD process in order to distinguish it from other (legitimate) processes that may appear similar in many respects. This effort leverages established Laboratory programs in intelligence analysis, chemical process modeling, and sensor development.

## **Protecting Against Chemical and Biological Attacks**

Terrorism using weapons of mass destruction poses a real and growing threat. Aum Shinrikyo, the terrorist group responsible for the sarin nerve gas attacks on the Tokyo subways, demonstrated with deadly clarity that terrorists can acquire and are willing to use WMD. Ramzi Yousef, the mastermind of the World Trade Center bombing, had also considered the use of chemical weapons. More recent incidents, like the Las Vegas anthrax scare, highlight the ready availability of biological materials and the reality of the bioterrorism threat.

### ***Biodetectors***

A limiting factor in the nation’s ability to protect against a biological terrorist attack is the current state of biodetector technology. As part of DOE’s Chemical and Biological Weapons Nonproliferation Program, we are developing two classes of biodetectors: immunofluorescence-based sensors (miniature flow-cytometers) and DNA-recognition instruments (based on the polymerase chain reaction, or PCR). This past year, we tested our new 10-chamber (10-sample parallel analysis) automated nucleic acid analyzer (ANAA) at the Dugway Proving Ground, Utah, in the Joint Field Trial IV, a Department of Defense-sponsored evaluation of front-running technologies for detecting biological warfare pathogens. ANAA is capable of autonomous operation from the point of a collected sample through sample preparation, PCR, DNA analysis, and reporting of results. On the basis of ANAA’s outstanding performance at this test, personnel from Naval Medical Research Institute were trained on its operation. ANAA was deployed to the Middle East in February

1998, with detection capabilities for nine pathogens, in support of possible U.S. troop deployment to the region.

### ***Forensics***

Government agencies are increasingly turning to our Forensic Science Center for forensic analyses and characterizations beyond the capabilities of their own laboratories. The Federal Bureau of Investigation (FBI) called upon us several times this past year to help in the characterization of smuggled nuclear contraband. For these instances, we performed the ancillary forensic analysis of the nuclear materials and made nuclear characterizations beyond the capabilities of the FBI's laboratory. In August 1998, the Forensic Science Center was formally named a west-coast support laboratory for the FBI. In addition, we continue to miniaturize and ruggedize forensic analysis technologies for field use. For example, we recently delivered to the FBI a field-portable gas chromatograph-mass spectrometer (GC-MS) that weighs approximately 50 pounds yet has the capabilities of a laboratory-scale instrument.

### ***Sensor Networks***

The Joint Biological Remote Early Warning System (JBREWS) is being developed for the Department of Defense's Joint Project Office for Bio-Defense to provide U.S. troops with early warning of a biological attack. This system combines a network of commercially available sensors with the military's communications assets. By networking the sensors, JBREWS can optimize their overall performance; improved sensors can be readily incorporated into JBREWS as they become available. By tying into the military's existing communications system, JBREWS takes advantage of well-established command and communications procedures. JBREWS is portable and flexibly deployable to locations where ground troops are deployed. Livermore's contributions to this project include advances in the algorithms, including application of an adaptive Kalman filter to the outputs of the particle-size sensors to improve background suppression and integration of network data. In a field test held this past summer, preparatory to the Advanced Concept Technology Demonstration (ACTD) scheduled for next year, JBREWS successfully demonstrated data collection from multiple sensors and integrated operations.

We are continuing to develop and refine our concept for a Wide Area Tracking System (WATS). Numerous studies indicate that covert ground delivery of a nuclear device may be a likely mode of terrorist attack. WATS uses an expandable array of unattended sensor units, linked to a central control station, and unique data-fusion techniques to detect, identify, and track a nuclear device or nuclear material package. Information from the sensor network can be integrated and combined with other available data such as traffic patterns and road connectivity (e.g., through an intelligent traffic management system). WATS is being evaluated for incorporation into national nuclear emergency response operations, and an extremely successful field test of a WATS-type network was conducted in early 1999.

### ***Bridging the Technology-Policy Gap***

Technical issues comprise only a portion of the nonproliferation and counterterrorism picture. Our Center for Global Security Research provides a bridge between the technology and policy communities, bringing technologists and policy people together to examine ways in which technology can enhance the international security framework. The Center does not advocate policy or programs; rather, it assembles teams of diverse experts who take fresh looks at problems involving the interaction and interface of technology and policy. Topics chosen for study leverage the talents and resources at Livermore and

utilizing unique capabilities brought to the Center by visiting scholars. The Center for Global Security Research collaborates with a broad spectrum of organizations engaged in similar work, including the University of California, other security research centers in academia, U.S. government agencies, and private institutions worldwide.

### ***Future of Nuclear Deterrence***

The Center partnered with the National Defense University in a study examining U.S. nuclear deterrence policy in light of the post-Cold War world. Participants included policy experts as well as nuclear scientists from the DOE weapons laboratories. The study identified important post-Cold War changes (a world with a single superpower, where Russia is less hostile than its predecessor state, and where other nuclear states, potential proliferants, and subnational groups have the ability to affect U.S. flexibility and security through the use of WMD). Its analysis took into account the dynamic economic globalization, regional areas of political integration and disintegration, the worldwide diffusion of technology, the potential spread of WMD, and the growing vulnerability of critical infrastructures. The study concluded by recommending a new paradigm for U.S. nuclear deterrence—one that emphasizes uncertainty management and requires a deeper and broader understanding of deterrence and its constituent components of dissuasion, denial/defense, and retaliation. This work aided a Defense Science Board study, which reached many of the same conclusions.

### ***Biological Weapons Monitoring***

The Center has sponsored a number of workshops addressing issues related to the proliferation, actual use, or threatened use of biological weapons. These workshops supported national security by clarifying critical issues, educating the scientific community about the needs of the policy community, and informing the policy community about the possibilities of science and technology. The most recent workshops, carried out in partnership with the Monterey Institute of International Studies, examined potential technologies and protocols that could strengthen the effectiveness of the Biological Weapons Convention. International participants from industry, governments, and academia focused, in particular, on the role and utility of sampling and inspection protocols. The study results were provided to the U.S. negotiating team on strengthening this arms control agreement.

## **INSTITUTIONAL ISSUES**

### **The Technical Staff and Attracting New Talent**

The key to the Laboratory's contribution to the successes in stockpile stewardship and nonproliferation that I have reported is the technical staff at Livermore. Demanding responsibilities require top-notch people and their expert judgment. We rely on having highly qualified and experienced people that are motivated by the opportunity to do something important for the country, technical challenges in their careers, and access to the tools needed to get the job done.

We face the absolutely crucial challenge of maintaining expert judgment about nuclear weapons issues—it underpins our efforts in both stockpile stewardship and nonproliferation. That challenge was recognized from the onset of the Stockpile Stewardship Program by this committee and those of us engaged in the program, and it has been very carefully considered by the Commission on Maintaining United States Nuclear Weapons Expertise (the “Chiles Commission”). The Commission has done an excellent job of consolidating workforce information across the DOE laboratory and production complex. They have correctly pointed out the need for a sustained recruiting and training effort at the laboratories to supplement our veteran workforce.

For stockpile stewardship to succeed we must move ahead with the program as rapidly and completely as possible. It is a race against time. Inside the next decade our nuclear-test veterans will be gone. We are counting on our current cadre of experienced scientists to help develop and install the new tools only now starting to come on line. The experienced hands are working with their successors—both training them and evaluating their skills. Activities such as dual revalidation, weapon physics code development, and life extension programs are both crucial to immediate stockpile needs and an opportunity for training. Evaluations of these mentoring efforts are an integral part of the program's self-assessment of the people and their capabilities in implementing the program.

So far, our efforts to bring fresh talent into national security programs at Livermore have had encouraging results. In FY 1998, we hired more new people into the stockpile stewardship program than in the previous two years combined. The nonproliferation, arms control, and international security program at the Laboratory has also had success in hiring new talent, but continuing growth of activities in this area makes the challenge greater than replacing staff retirements. Moreover, we have increased our recruiting efforts, including the establishment last year of a prestigious new fellowship program at the Laboratory, the Lawrence Livermore Fellows. Even so, the three most crucial factors for attracting new talent remain service to the country, exciting technical challenges, and program stability.

Other factors are also important. The multidisciplinary, multiprogram character of Livermore increases the diversity of scientists and engineers who are attracted to the Laboratory. Some of these researchers who have had no initial exposure to the existing opportunities and challenges are drawn into careers that directly support stockpile stewardship or nonproliferation. Others augment the technical base needed for national security programs even though their research is focused in other areas; and yet others achieve innovations that lead to important spin-offs for national security. In addition, the Laboratory's association with the University of California (UC), which includes a variety of joint research projects with campuses as well as a branch of UC Davis and a number of UC research institutes at the Livermore site, is attractive to prospective employees and helps to provide a pipeline of new talent. ASCI's Academic Strategic Alliances Program also helps by strengthening U.S. academic programs in high-performance scientific computing and fostering closer ties with universities, which provide a major source of new

talent for the Laboratory. Finally, Livermore's Laboratory-Directed Research and Development (LDRD) Program, which advances science and technology in support of our national security mission, also provides an important vehicle for bringing new talent to Livermore through collaborative research and postdoctoral opportunities.

I am optimistic that Livermore will be able to attract and retain the talent the nation needs to combat WMD proliferation and terrorism and maintain stockpile safety and reliability in the early 21st century. Yet, this is a matter that needs continuing attention.

### **Managing R&D in a Global Science and Technology Community**

As I have discussed, as part of our nonproliferation efforts, we participate in international efforts to prevent the spread of nuclear, chemical, and biological weapons, materials, and know-how. We also develop technologies to monitor international agreements and have ongoing efforts to evaluate foreign weapons programs. More generally, as a DOE national laboratory, our work is at the forefront of science and technology and thus we must stay at the leading edge in areas central to our programs. We depend on interactions with the international scientific community to be cognizant of major advances and to acquire special expertise needed to accomplish our mission goals. These interactions—as well as the Laboratory's strong ties to the University of California (and other universities) and selected sectors of U.S. industry—necessarily make the Laboratory part of the global research and development community.

When we interact with foreign nationals on site or off site, we take the issue of protecting sensitive information extremely seriously. We fully appreciate that there is a risk of compromise of sensitive information if effective steps are not taken to understand the potential threat and to implement appropriate controls. We employ sophisticated measures in the way we ensure information security, process and manage foreign nationals on site, and prepare Laboratory employees for foreign travel. I believe we have effective procedures and controls in place. However, we recognize that circumstances change, and we continually reevaluate, modify, and upgrade our security systems as necessary.

A key component of Livermore's security efforts is our counterintelligence program, which was established in 1986. Our counterintelligence program develops threat assessments for the Laboratory, reviews proposed visits and assignments by foreign nationals, and runs a vigorous Laboratory-wide counterespionage awareness program. The program manager was hired from the ranks of the Federal Bureau of Investigation (FBI) to place our counterintelligence program in close coordination with the lead agency for foreign counterintelligence in the U.S. Additional former FBI Special Agents have since been hired into the program. We have established a very close and effective working relationship with the FBI, to the benefit of the Laboratory, the DOE, and the Bureau.

In February 1998, a Presidential Decision Directive (PDD-61) mandated a new, more vigorous counterintelligence program for DOE. The program is headed by an FBI special agent, who took office in April and examined the counterintelligence programs at all the laboratories. Features of Livermore's program are providing direction for the development of DOE-wide programs and procedures. We are working with DOE to help strengthen counterintelligence throughout the Department and we are taking specific steps to enhance Livermore's program. For example, an additional former FBI agent is being hired; within a month there will be a total of five experienced counterintelligence officers at the Laboratory. We also have brought on line our new web-based, foreign Visitor Tracking System (VTS) to make reports of foreign visits more timely and readily available for analysis. These additions, together with implementation of a number of enhanced internal procedures, should enable us to meet the goals set out in PDD-61.



## SUMMARY REMARKS

The Stockpile Stewardship Program is working. It has greatly benefited from strong Congressional support, effective integrated program planning and implementation, and the dedicated efforts of program personnel. We are executing detailed program implementation plans that depend on strong partnerships among the laboratories, the production facilities, the Nevada Test Site, and U.S. industry. Furthermore, formal certification procedures and review processes are in place and functioning to assure the nation that the stockpile remains safe and reliable in the absence of nuclear testing. The Secretaries of Energy and Defense provided such assurances in the third annual certification in December 1998.

The annual certifications depend on scientific activities to demonstrate weapon performance at the component level and provide integrated assessments of overall performance. The Stockpile Stewardship Program both backs up the annual certifications and prepares us for a future in which stockpile assurance will become an even greater challenge. We can point to many specific recent accomplishments: considerable progress in developing a basis for understanding aging effects in weapon materials, effective use of the computational and experimental tools we have in addressing current stockpile issues, and success in the program to extend the stockpile life of the W87 warhead. Furthermore, as part of the Accelerated Strategic Computing Initiative (ASCI), we have taken delivery and are using the 3.9-TeraOPS IBM Blue Pacific supercomputer. In addition, we are proceeding on schedule with the acquisition of even more powerful computers and the construction of the National Ignition Facility (NIF). These tools are needed to better assess weapon performance and train the next generation of stockpile stewards.

The greatest challenges still lie ahead. The demands on the Stockpile Stewardship Program will continue to grow as weapons in the enduring stockpile continue to age. The U.S. nuclear weapons stockpile is older on average than it has ever been. The reservoir of nuclear test and design experience at the laboratories continues to diminish. Program success depends on bringing into operation scientific capabilities such as ASCI and NIF while there remain experienced nuclear designers to train the next generation of stockpile stewards. Maintenance of a safe and reliable nuclear weapons stockpile requires sustained support for the program from Congress and the Administration. Accordingly, I urge your strong support of the FY 2000 budget submission for Defense Programs.

I also urge your vigorous support for the program proposed by the Office of Nonproliferation and National Security and for the programs and initiatives of other agencies in the area of WMD nonproliferation and counterterrorism. The enormity of the challenge cannot be overstated. In the past year, the U.S. has taken military action against those believed responsible for the U.S. embassy bombings in Africa and against Saddam Hussein in response to his noncompliance with UN resolutions and the regional threat he poses. The nation continues to face the very real threat of WMD terrorism.

The proliferation of weapons of mass destruction can only be halted with a multilayered defense that integrates technology and policy across the entire spectrum of the threat—the sources of weapons materials, technology, and expertise, the potential proliferators, and the rogue states and terrorists. As I have highlighted, Livermore is making significant progress in technologies to secure weapons-usable fissile materials and detect proliferation-related activities. The DOE program for FY 2000 includes increased support for cooperative engagement with Russia, fissile materials disposition, and chemical and biological agent detection. We have the capabilities and the drive to make essential contributions to the nation's efforts to halt WMD proliferation, counter WMD terrorism, and combat emerging threats to national security.